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(54) **ADAPTIVE QUALITY OF SERVICE POLICY FOR DYNAMIC NETWORKS**

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(52) **U.S. Cl.** **370/230**

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See application file for complete search history.

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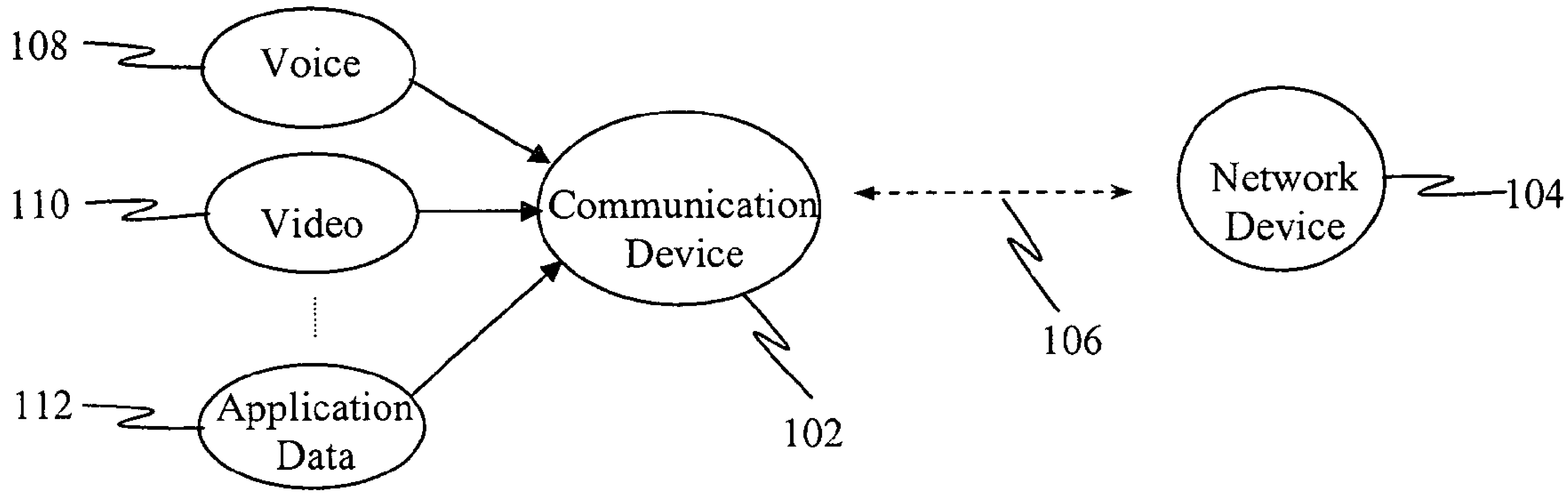
(57) **ABSTRACT**

A close-loop quality of service system is provided that collects real-time network performance indicators at the physical, data link and network layers. Using those indicators, the system dynamically controls the network traffic in order to achieve improved performance according to the priority and policy defined by a data user or system/network administrator. Several features of this quality of service system includes (1) dynamic maximum bandwidth reallocation, (2) dynamic maximum packet sizing, (3) adaptive policing, and/or (4) real-time link status feedbacks to make more efficient use of available bandwidth and adjust to transmission requirements.

36 Claims, 6 Drawing Sheets



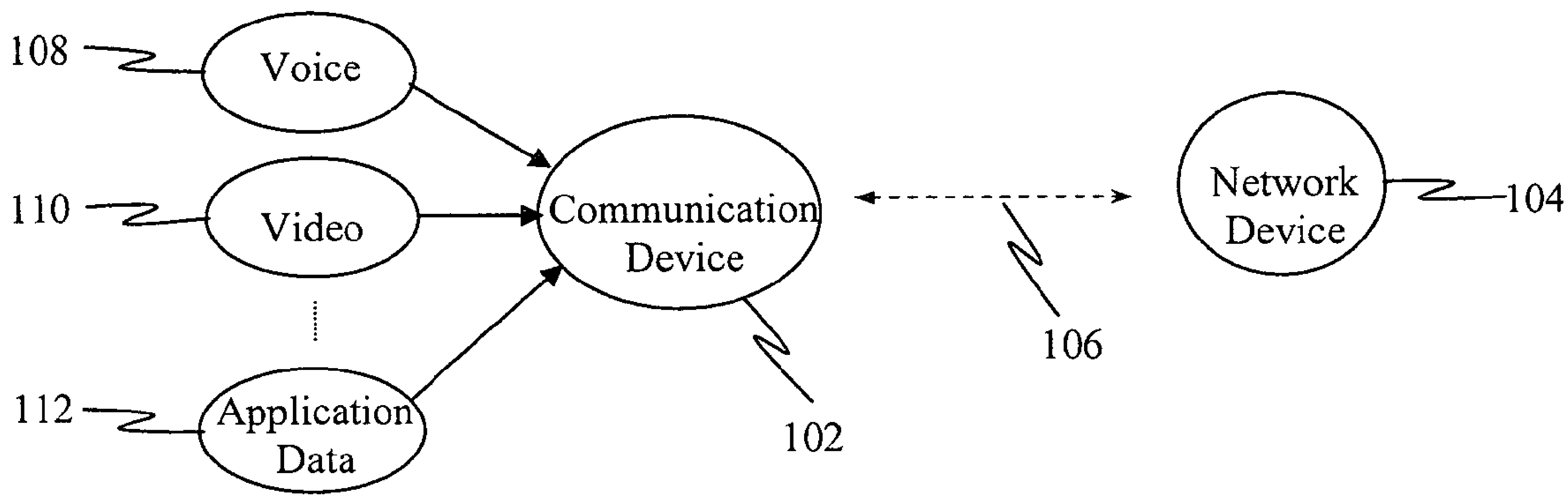


Figure 1

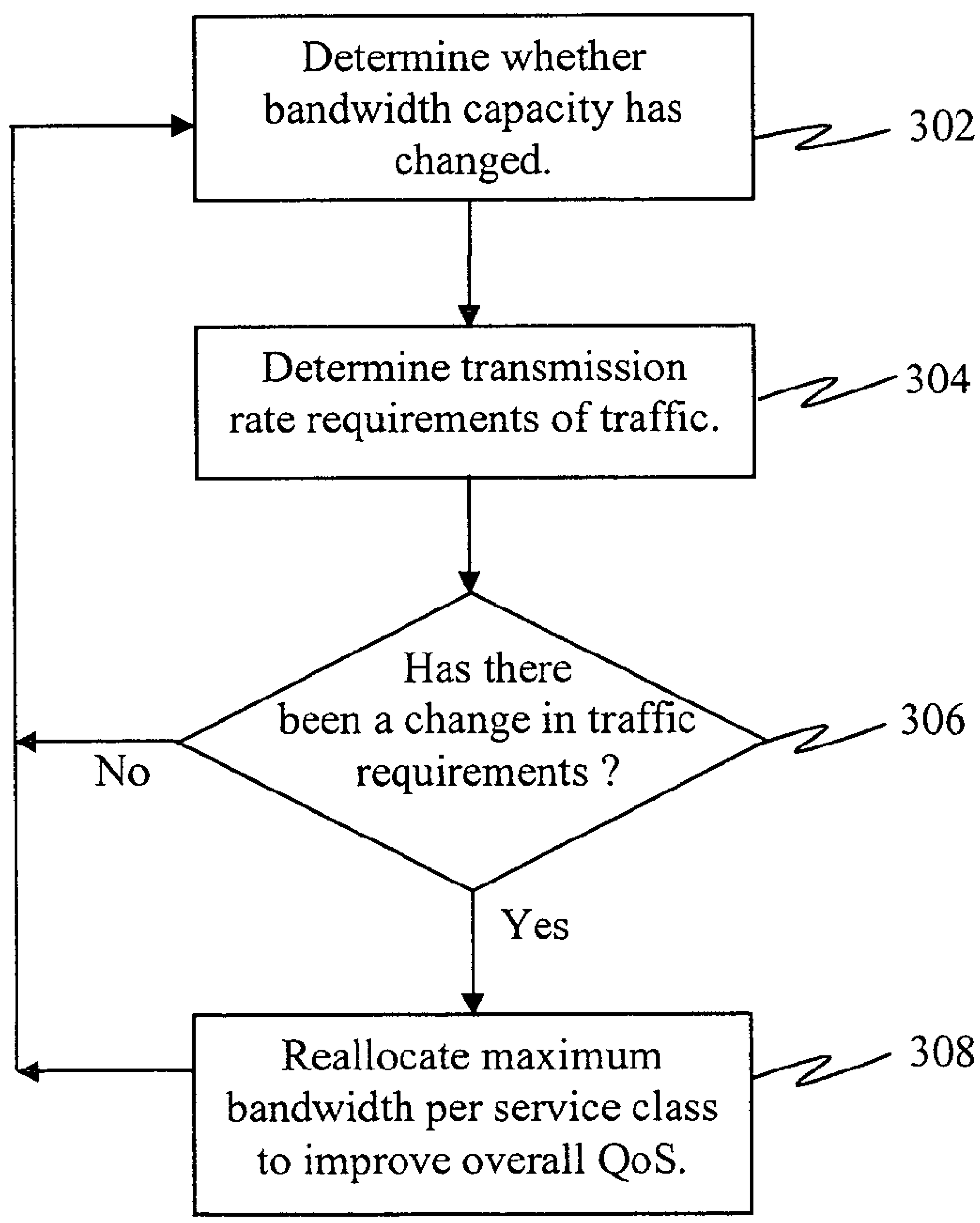


Figure 3

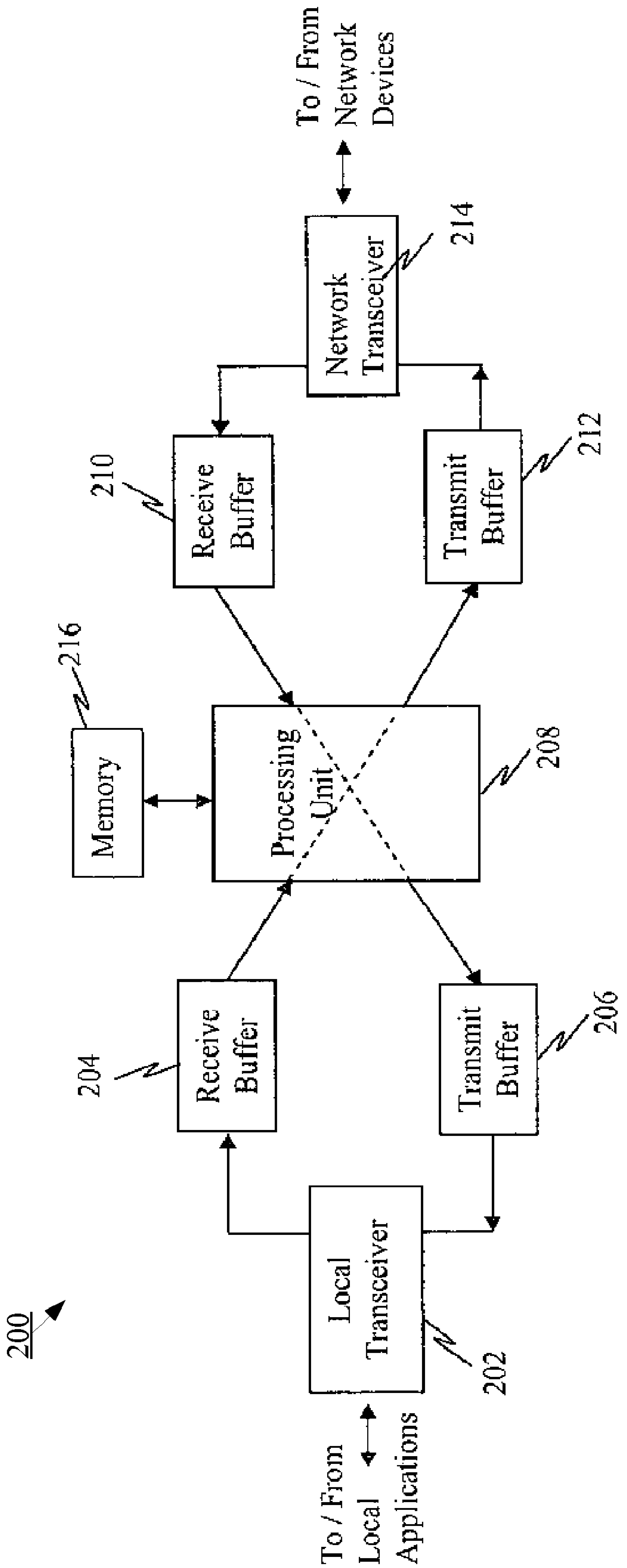

200
To / From
Local
Applications
Local
Transceiver
202
Receive
Buffer
204
Transmit
Buffer
206
Processing
Unit
208
Memory
216
Receive
Buffer
210
Transmit
Buffer
212
Network
Transceiver
214
To / From
Network
Devices

Figure 2

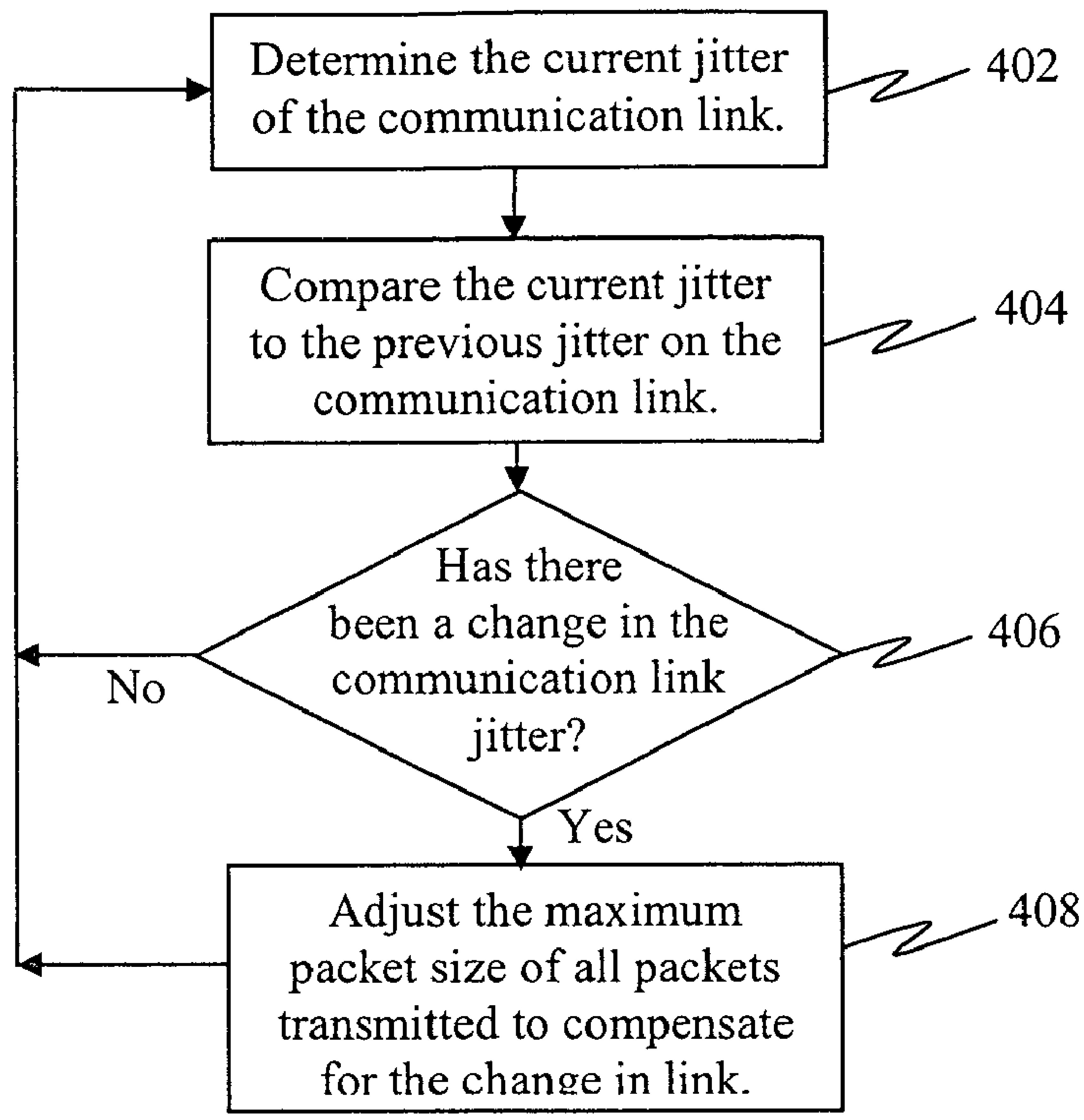


Figure 4

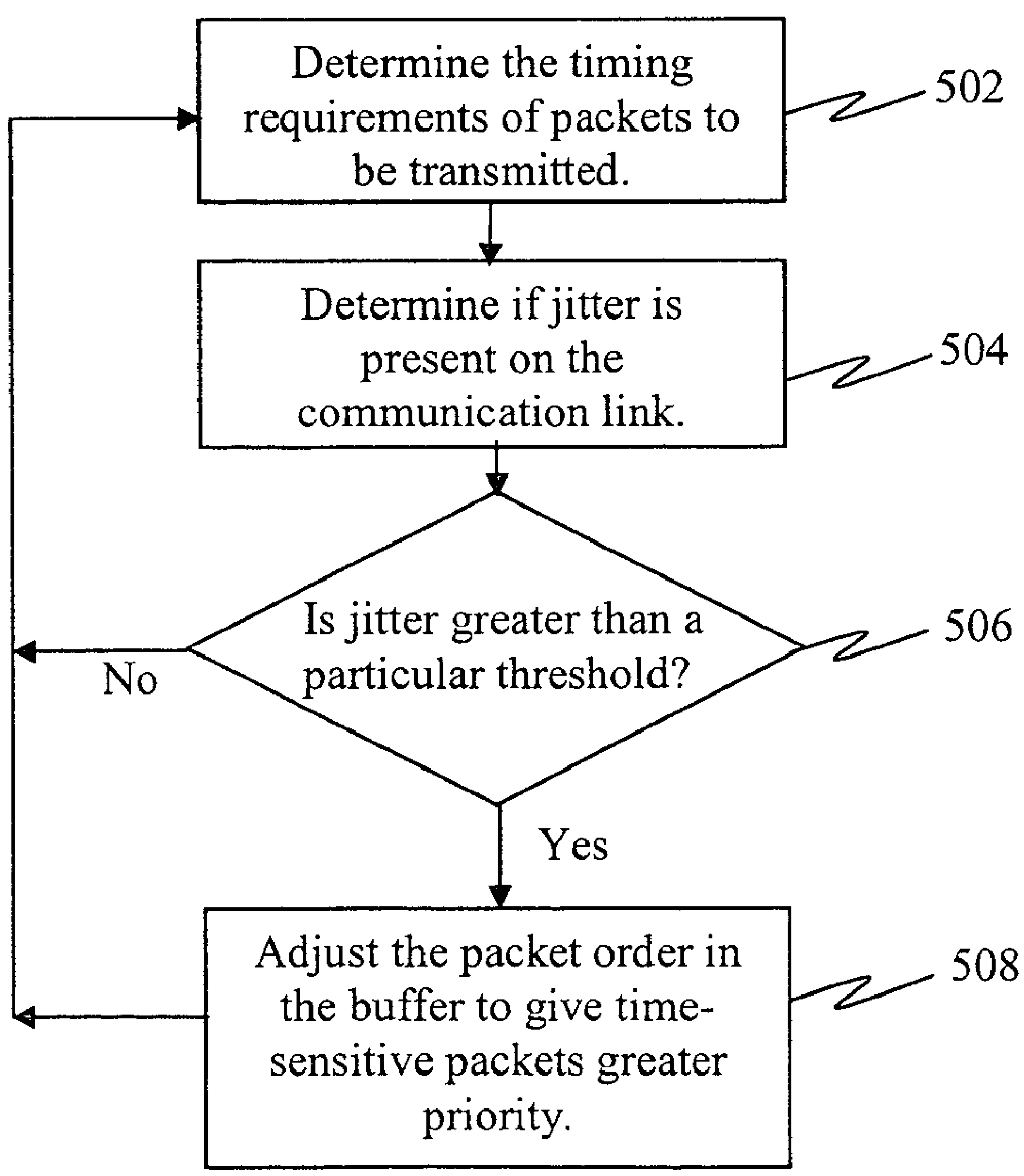


Figure 5

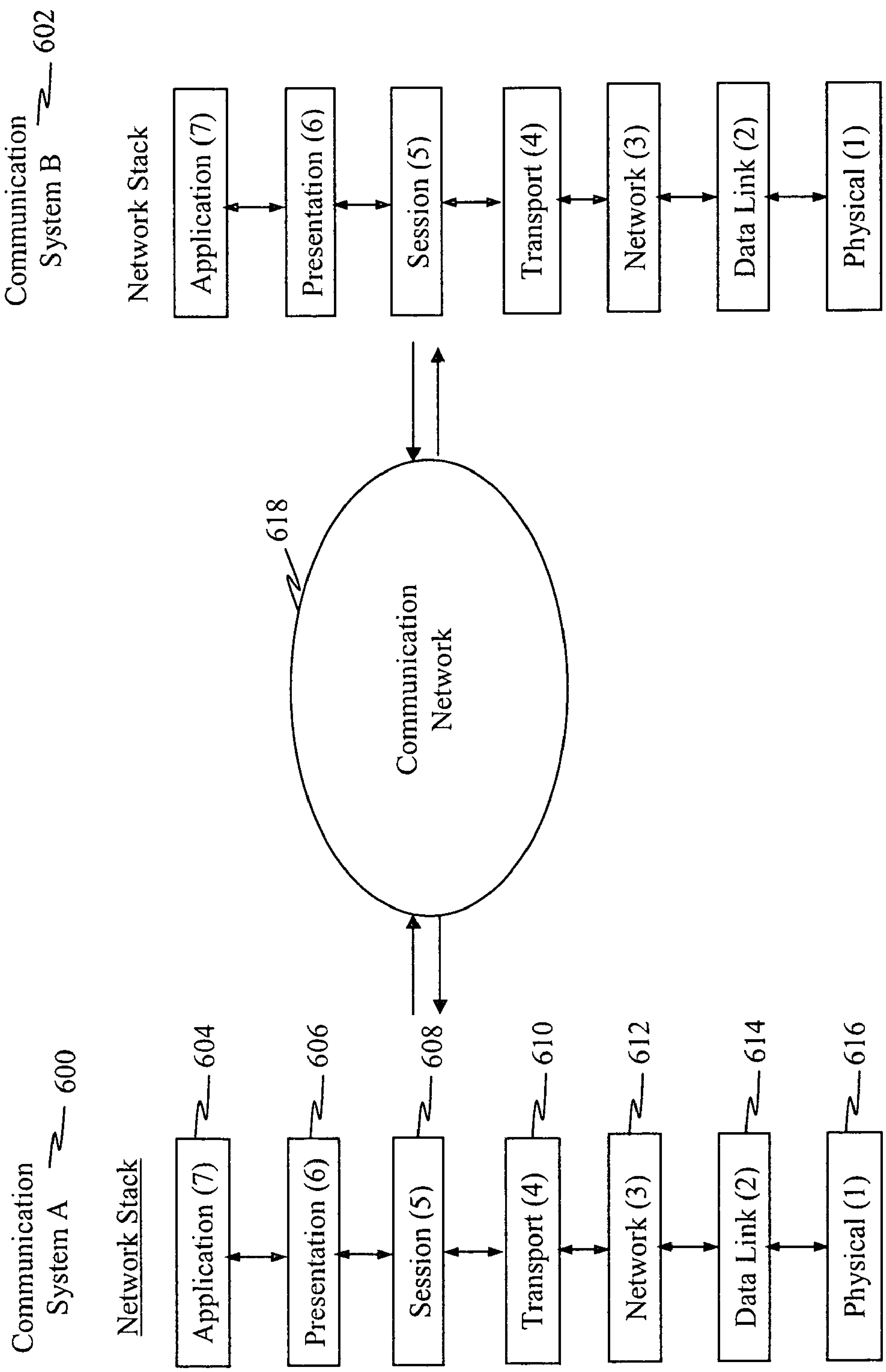

Communication System A
600
Network Stack
Application (7)
604
Presentation (6)
606
Session (5)
608
Transport (4)
610
Network (3)
612
Data Link (2)
614
Physical (1)
616
Communication Network
618
Communication System B
602
Network Stack
Application (7)
Presentation (6)
Session (5)
Transport (4)
Network (3)
Data Link (2)
Physical (1)

Figure 6

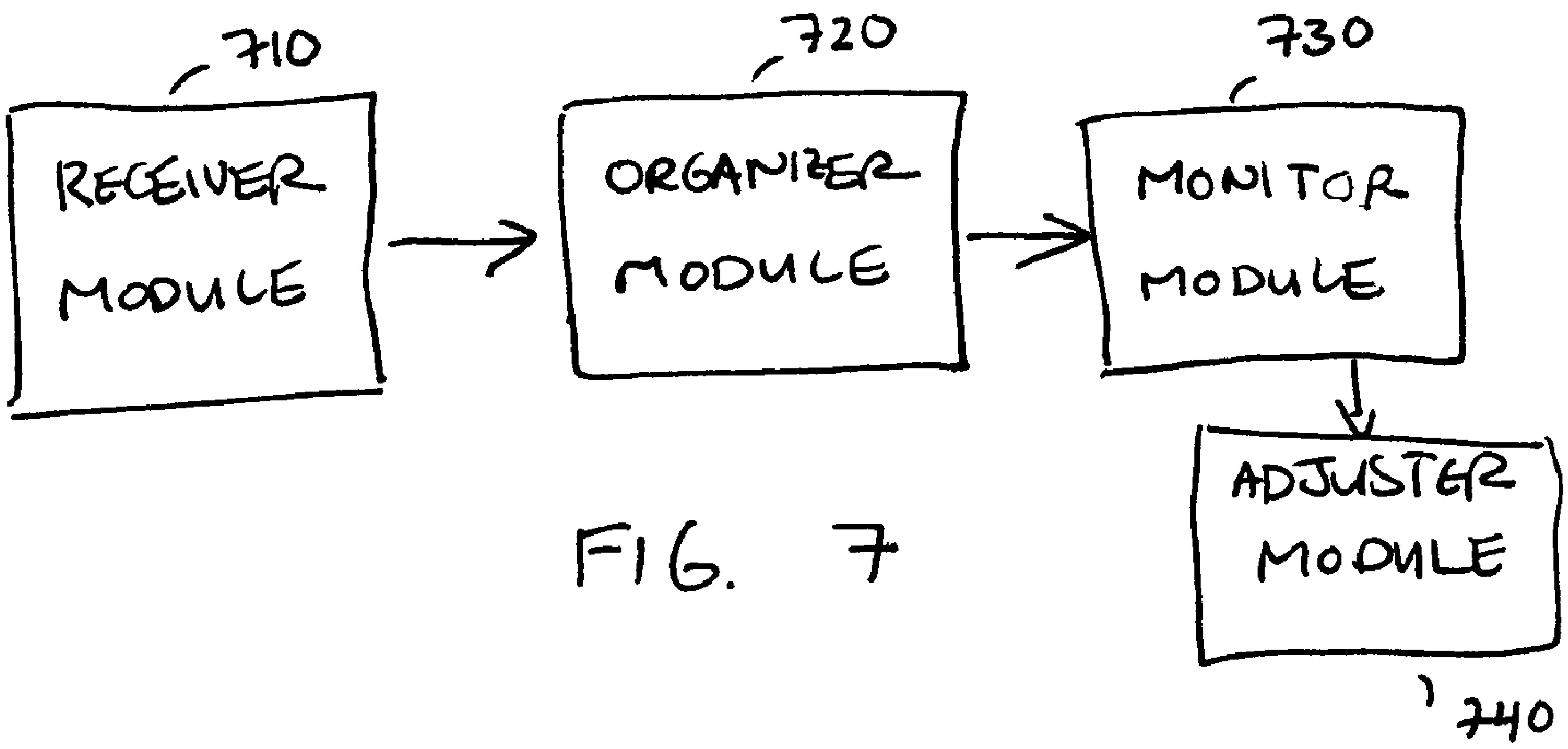


FIG. 7

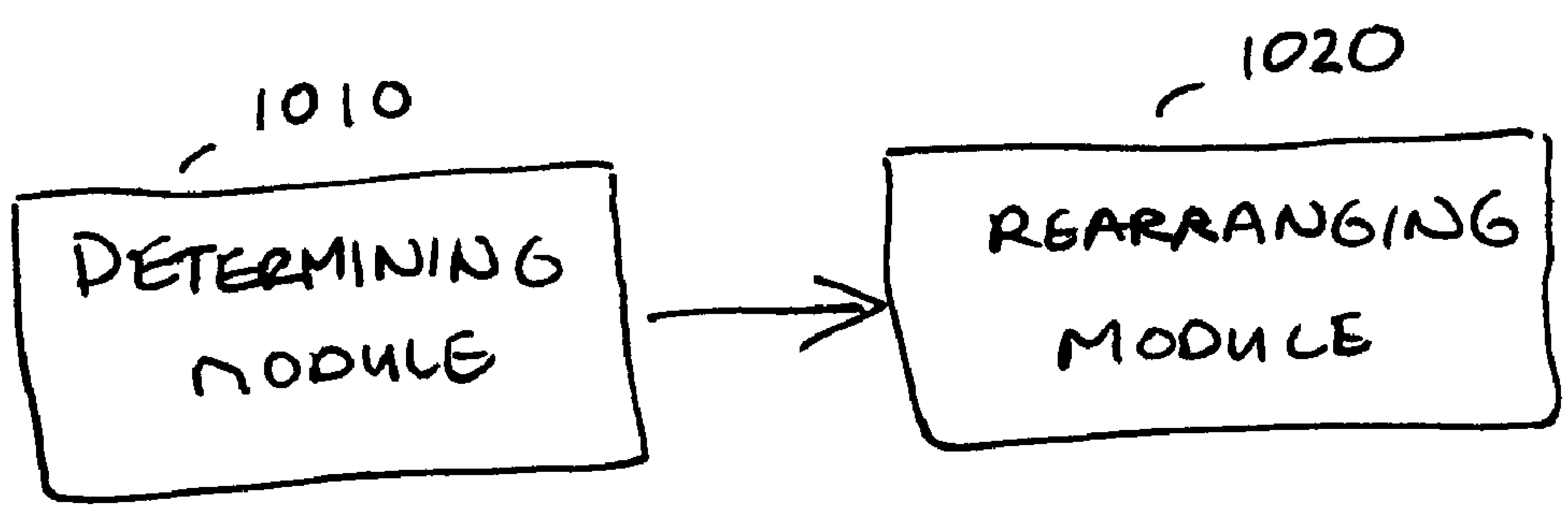


FIG. 10

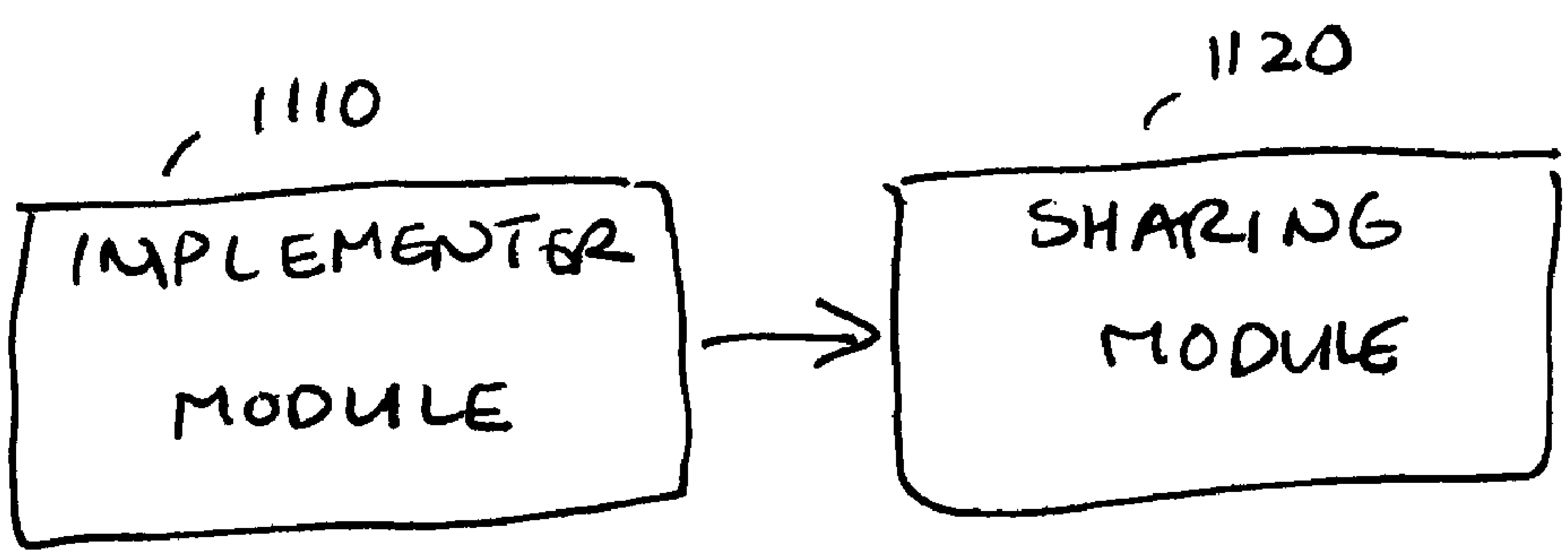


FIG. 11

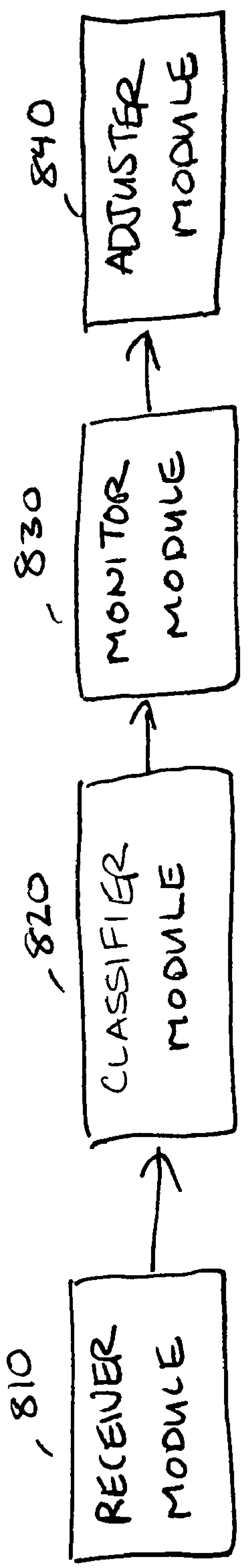

810
RECEIVER MODULE
820
CLASSIFIER MODULE
830
MONITOR MODULE
840
ADJUSTER MODULE

FIG. 8

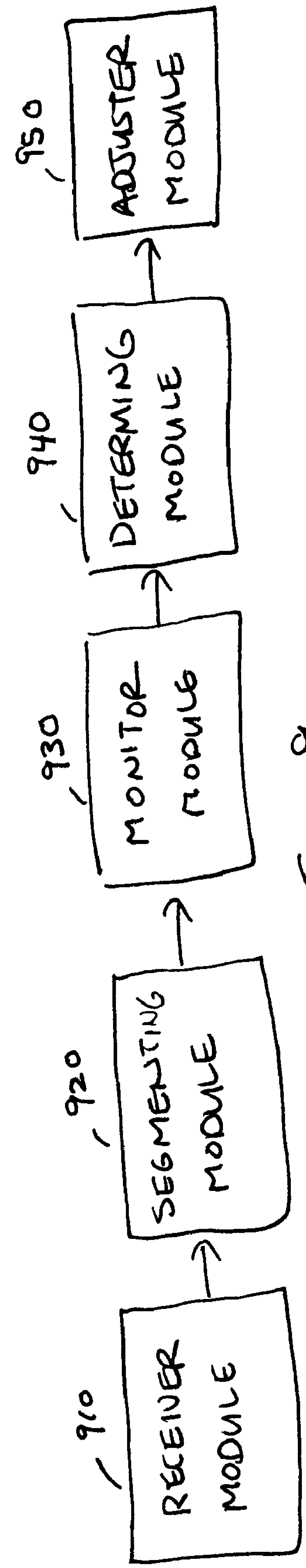

910
RECEIVER MODULE
920
SEGMENTING MODULE
930
MONITOR MODULE
940
DETERMINING MODULE
950
ADJUSTER MODULE

FIG. 9

ADAPTIVE QUALITY OF SERVICE POLICY FOR DYNAMIC NETWORKS

BACKGROUND

1. Field

Various features pertain to communication and/or data networks. At least one implementation pertains to a method, system, and device for providing quality of service information to adaptively allocate network resources and modify traffic and priority policy.

2. Background

Communication networks serve to transfer various types of information including data, voice, audio, video, or other forms of content and control signals. The Open System Interconnection (OSI) model provides structured layers to implement communications across a network. The OSI layers define standards at each level of the network: physical (layer 1), data link (layer 2), network (layer 3), transport (layer 4), session (layer 5), presentation (layer 6), and application (layer 7).

Because networks have a limited bandwidth through which to transfer this information, they typically prioritize the order in which information is transmitted. This prioritizing of information on a network is commonly used to guarantee a quality of service (QoS) or the particular type of transmission (e.g., data, voice, video, etc.). For example, time-sensitive information, such as voice packets for a telephonic call, may be given priority over less time-sensitive information, such as text messages.

The current technique to configure QoS support during setup of a given network is to specify the committed bandwidth and priority for each type of service. This works well on a network that has static bandwidth with stable link speed, and known or predictable latency and packet loss characteristics. Conventional QoS techniques typically assume a dedicated link speed, such as a T1 connection providing 1.5 Mbps or ADSL connection operating at about 100 Kbps. Bandwidth usage configuration usually happens during the setup of QoS policy and is not easily adjustable after that point. A static link speed is assumed and used for rate-limiting configuration of one more service classes. No real-time feedback is available to make QoS policy adjustments when the bandwidth changes dynamically. This creates problems in implementing QoS when the link speed changes, as would be the case where the link degrades for instance. Thus, conventional QoS policy configurations are conservative in their bandwidth allocations and wasteful of network resources, or overly ambitious in their bandwidth allocations and perform poorly in adverse link conditions.

For a network that has dynamic bandwidth characteristics, such as a wireless network (e.g., an evolutionary data optimized (EVDO) network), the current QoS policy techniques would either be ineffective to police the traffic or require an administrator to be way too conservative, and therefore wasteful, with the precious network resources. That is, in networks where the bandwidth may vary or the amount and types of information transferred are unpredictable, it becomes difficult to allocate bandwidth among the services (e.g., data, voice, video, control signals, etc.) supported.

SUMMARY

A close-loop QoS system is provided at the network layer to collect real-time network performance indicators at the physical, data link and network layers. Using those indicators, the system dynamically controls the network traffic in order to achieve improved performance according to the priority and policy defined by a data user or system/network administrator. Several features of this QoS system includes (1) dynamic maximum bandwidth reallocation, (2) dynamic maximum packet sizing, (3) adaptive policing, and/or (4) real-time link status feedbacks to make more efficient use of available bandwidth and adjust to transmission requirements.

An apparatus is provided comprising an input interface to receive digital information and a processing unit coupled to the input interface, the processing unit configured to (a) organize the digital information into packets, each packet associated with one of a plurality of service classes, (b) monitor real-time characteristics of a dynamic communication link to identify a change in bandwidth, and (c) if the bandwidth of the dynamic communication link changes, dynamically adjust a quality of service policy to reallocate the maximum bandwidth per service class. The processing unit is further configured to transmit the packets according to the quality of service policy. Additionally, the processing unit is further configured to (a) determine whether jitter on the dynamic communication link has changed, and (b) if the jitter has changed, adjust the maximum packet size of transmitted packets to maintain a maximum packet transmission time approximately constant. In another embodiment, the processing unit is further configured to (a) determine whether jitter is present in the dynamic communication link, and (b) if jitter is present, rearrange the priority order of one or more service classes to give time-sensitive digital information greater priority.

Another embodiment provides a communication gateway comprising (a) means for receiving digital information, (b) means for organizing the digital information into packets, each packet associated with one of a plurality of service classes, (c) means for monitoring real-time characteristics of a dynamic communication link to identify a change in bandwidth, and (d) if the bandwidth of the dynamic communication link changes, means for dynamically adjusting a quality of service policy to reallocate the maximum bandwidth per service class.

A method for adaptive bandwidth reallocation for quality of service policy of a dynamic communication link is also provided comprising (a) receiving digital information from one or more sources, (b) organizing the digital information into packets, each packet associated with one of a plurality of service classes, (c) dynamically adjusting a quality of service policy to reallocate the maximum bandwidth per service class if the bandwidth of the dynamic communication link changes, and (d) transmitting the packets according to a predefined quality of service policy. The method further comprises monitoring the real-time bandwidth characteristics of the dynamic communication link. The delivery priority level associated with each packet is determined by the timing requirements of the digital information contained in the packet. The method further comprises (a) dynamically adjusting a maximum packet size for the packets to maintain a maximum packet transmission time across the dynamic communication link approximately constant, and (b) rearranging the order of packets to give time-sensitive packets greater priority if jitter is present.

Another embodiment provides a machine-readable medium having one or more instructions for dynamically adjusting maximum bandwidth allocations of a communication system, which when executed by a processor causes the processor to (a) receive digital information, (b) classify the digital information into one or more service classes, (c) monitor real-time characteristics of a dynamic communication link having varying bandwidth, and (d) dynamically adjust a quality of service policy for the one or more service classes according to the real-time characteristics of the dynamic communication link. The quality of service is adjusted if the bandwidth of the dynamic communication link changes. Additionally, dynamically adjusting the quality of service policy of the one or more service classes may also include (a) proportionally reallocating a total bandwidth of the dynamic communication link according to previous maximum allocation percentages, (b) reallocating a total bandwidth of the dynamic communication link according to current traffic demands over the dynamic communication link, (c) denying service to new digital information in a service class if the allocated bandwidth is insufficient to support the minimum transmission rate for existing digital information in the service class, (d) allocating a maximum bandwidth for each service class that is equal to or greater than a minimum bandwidth necessary to support minimum transmission rates of information in each service class, and/or (e) denying service to new digital information in a service class if the allocated bandwidth for the service class is insufficient to support the minimum transmission rate for existing digital information in the service class. The machine-readable medium may further comprise one or more instructions for (a) segmenting the digital information into packets, and (b) transmitting the packets over the dynamic communication link according to the quality of service policy. The quality of service policy is set at a network layer of a network stack. The machine-readable medium may further comprise one or more instructions for (a) determining whether jitter on the dynamic communication link has changed, and (b) if the jitter has changed, adjusting the maximum packet size of the digital information to maintain a maximum packet transmission time approximately constant. In another embodiment, the machine-readable medium may further comprise one or more instructions to (a) determine whether jitter is present in the dynamic communication link, and (b) if jitter is present, rearrange the priority order of one or more service classes to give time-sensitive digital information greater priority. The machine-readable medium may further comprise one or more instructions to (a) implement two or more network stack layers to transmit digital information from one or more service classes across the dynamic communication link, and (b) share dynamic link status information from a first network stack layer with a second network stack layer. The dynamic link status information is shared from either the physical layer or data link layer with the network layer.

Another embodiment provides a machine-readable medium having one or more instructions for implementing dynamic maximum packet sizing, which when executed by a processor causes the processor to (a) receive digital information, (b) segment the digital information into packets (c) monitor real-time characteristics of a dynamic communication link having varying bandwidth, (d) determine if timing jitter of the dynamic communication link has changed, (e) and dynamically adjust a maximum packet length of the digital information to maintain a maximum packet transmission time approximately constant. The machine-readable medium further comprises one or more instructions to (a) determine whether jitter in the dynamic communication link has changed.

Yet another embodiment provides a machine-readable medium having one or more instructions for implementing adaptive policing of digital information packets, which when executed by a processor causes the processor to (a) determine whether jitter is present in a dynamic communication link, and (b) rearrange the order of digital information packets to give time-sensitive packets greater priority when jitter is present. The machine-readable medium further comprises one or more instructions to determine delivery priorities of a plurality of digital information packets.

Another embodiment provides a machine-readable medium having one or more instructions for sharing dynamic link status information across two or more network stack layers, which when executed by a processor causes the processor to (a) implement two or more network stack layers to transmit digital information of one or more service classes across the dynamic communication link; and (b) share dynamic link status information from a first network stack layer with a second network stack layer. The first network stack layer is either the physical layer or data link layer of a network stack and the second network stack layer is the network layer. The machine-readable medium further comprises one or more instructions to obtain real-time link status feedback from a data link layer of the network stack and apply it to quality of service operations at the network layer of the network stack.

Several of the described features may also be implemented as part of one or more apparatus or devices. For example, an apparatus may comprise (a) a receiver/device for receiving digital information; (b) a classifying circuit/device for classifying the digital information into one or more service classes; (c) a monitoring circuit/device for monitoring real-time characteristics of a dynamic communication link having varying bandwidth; and (d) a circuit/device for dynamically adjusting a quality of service policy for the one or more service classes according to the real-time characteristics of the dynamic communication link. Another example provides an apparatus comprising (a) a receiver/device for receiving digital information; (b) a segmenting circuit/device for segmenting the digital information into packets; (c) a monitoring circuit for monitoring real-time characteristics of a dynamic communication link having varying bandwidth; (d) a circuit/device for determining if timing jitter of the dynamic communication link has changed; and (e) an adjusting circuit/device for dynamically adjusting a maximum packet length of the digital information to maintain a maximum packet transmission time approximately constant. Another example provides an apparatus comprising (a) first circuit/device for determining whether jitter is present in a dynamic communication link; and (b) a second circuit/device for adaptively rearranging the order of digital information packets to give time-sensitive packets greater priority when jitter is present. Yet another example provides an apparatus comprising (a) a first circuit/device for implementing two or more network stack layers to transmit digital information from one or more service classes across a dynamic communication link; and (b) a second circuit/device for sharing dynamic link status information from a first network stack layer with a second network stack layer.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a communication system in which dynamic bandwidth and/or traffic reallocation policy adjustments may be implemented.

FIG. **2** illustrates is a block diagram of one implementation of a communication device **200** that may be employed to perform bandwidth and/or traffic reallocation and policy adjustments.

FIG. **3** illustrates a method for adjusting the maximum bandwidth usage per service class on a gateway when dynamic bandwidth changes occur.

FIG. **4** illustrates a method for dynamic packet maximum sizing that may be implemented on a gateway to adjust QoS policy.

FIG. **5** illustrates a method for adaptive policing that may be implemented on a gateway to adjust QoS policy.

FIG. **6** illustrates one example of a communication system configured to provide adaptive quality of service at a first and/or second communication devices by implementing link status information across a network stack.

FIG. **7-11** illustrate other example apparatus that may be employed.

DETAILED DESCRIPTION

In the following description, specific details are given to provide a thorough understanding of the embodiments. However, it will be understood by one of ordinary skill in the art that the embodiments may be practiced without these specific detail. For example, circuits may be shown in block diagrams in order not to obscure the embodiments in unnecessary detail. In other instances, well-known circuits, structures and techniques may be shown in detail in order not to obscure the embodiments.

Also, it is noted that the embodiments may be described as a process that is depicted as a flowchart, a flow diagram, a structure diagram, or a block diagram. Although a flowchart may describe the operations as a sequential process, many of the operations can be performed in parallel or concurrently. In addition, the order of the operations may be rearranged. A process is terminated when its operations are completed. A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, etc. When a process corresponds to a function, its termination corresponds to a return of the function to the calling function or the main function.

Moreover, a storage medium may represent one or more devices for storing data, including read-only memory (ROM), random access memory (RAM), magnetic disk storage mediums, optical storage mediums, flash memory devices and/or other machine readable mediums for storing information. The term "machine readable medium" includes, but is not limited to portable or fixed storage devices, optical storage devices, wireless channels and various other mediums capable of storing, containing or carrying instruction(s) and/or data.

Furthermore, embodiments may be implemented by hardware, software, firmware, middleware, microcode, or any combination thereof. When implemented in software, firmware, middleware or microcode, the program code or code segments to perform the necessary tasks may be stored in a machine-readable medium such as a storage medium or other storage(s). A processor may perform the necessary tasks. A code segment may represent a procedure, a function, a subprogram, a program, a routine, a subroutine, a module, a software package, a class, or any combination of instructions, data structures, or program statements. A code segment may be coupled to another code segment or a hardware circuit by passing and/or receiving information, data, arguments, parameters, or memory contents. Information, arguments, parameters, data, etc. may be passed, forwarded, or transmitted via any suitable means including memory sharing, message passing, token passing, network transmission, etc.

One feature provides quality of service (QoS) support according to predefined policies on networks that have dynamic bandwidth, network latency and/or packet loss rates. One implementation of the QoS scheme is applied on top of the physical network to adapt to the real-time characteristics of the network and adjust the priority of different services dynamically based on pre-set policies.

A close-loop QoS system is provided at the network layer to collect real-time network performance indicators at the physical, data link and network layers. Using those indicators, the system dynamically controls the network traffic in order to achieve improved performance according to the priority and policy defined by a data user or system/network administrator. Several features of this QoS system includes (1) dynamic maximum bandwidth reallocation, (2) dynamic maximum packet sizing, (3) adaptive policing, and/or (4) real-time link status feedbacks to make more efficient use of available bandwidth and adjust to transmission requirements.

FIG. **1** illustrates a communication system in which dynamic bandwidth and/or traffic reallocation and policy adjustments may be implemented. One situation in which a dynamic bandwidth may be encountered is where some portion of the communications is performed over a wireless link. For example, a network communication device **102** wirelessly communicates with other network devices **104** via a wireless communication link/interface **106**. Communication device **102** may be a server configured to operate as a gateway, router, bridge, and/or repeater, that communicatively links one or more user devices **108**, **110**, **112** (e.g., phones, computers, personal communication devices, personal digital assistants, web browsers, etc.) to the rest of the network (e.g., network device **104**). The links between communication device **102** and the user devices **108**, **110**, **112** may be either wireless or wired. Generally, communication device **102** receives information from user devices **108**, **110**, **112** and forwards it over wireless link **106** to network device **104**. Similarly, communication device **102** receives information over wireless link **106** and distributes it to the appropriate recipient user device **108**, **110**, **112**.

Network device **104** may be a server configured to operate as a gateway, router, bridge, and/or repeater. Both communication device **102** and network device **104** may act as gateways for different subnets. In one implementation, traffic control QoS policy and advanced routing is applied at communication device **102** and network device **104** to control traffic in both directions. Generic routing encapsulation (GRE) may be applied at each end (communication device **102** and network device **104**) and a tunnel built between communication device **102** and network device **104**.

In one implementation, communication device **102** is located on an aircraft and communicates with various types of user devices **108**, **110**, **112** on the aircraft. Communication device **102** may act as a gateway to communicate with other wired or wireless networks (e.g., via gateway **104**). In this manner, user devices **108**, **110**, **112** are able to communicate beyond the aircraft even when the aircraft is in flight. Network device **104** may be a ground-based or air-borne gateway which enables communications with other ground-base or air-borne user devices or gateways.

FIG. **2** illustrates is a block diagram of one implementation of a communication device **200** that may be employed to perform bandwidth and/or traffic reallocation and policy adjustments. Communication device **200** may be used as communication device **102** in FIG. **1**, and function as a modem, gateway, or network interface to provide a network link for one or more local applications and/or devices. Communication device **200** includes a local transceiver **202** and a corresponding first set of receive and transmit buffers **204** and **206** communicatively coupled to a processing unit **208**. The processing unit **208** is also communicatively coupled to a second set of receive and transmit buffers **210** and **212** which are coupled to a network transceiver **214**. The processing unit **208** manages traffic between the local transceiver **202** and network transceiver **214** and may be configured to implement several features, including (1) dynamic maximum bandwidth reallocation, (2) dynamic maximum packet sizing, (3) adaptive policing, and/or (4) real-time link status feedbacks to make more efficient use of available bandwidth (through the communication link of the network transceiver **214**) on and adjust to transmission requirements. A memory device **216** may be coupled to the processing unit **208** to facilitate these traffic management functions. Note that one or more of the components and functions illustrated in FIG. **2** may be combined into a single component or embodied in several components without departing from the invention.

FIG. **3** illustrates a method for adjusting the maximum bandwidth usage per service class on a gateway, such as communication device **102**, when dynamic bandwidth changes occur. As the distribution or types of applications communicating through communication device **102** changes, it becomes wasteful to fix the bandwidth allocation to some set rate. Thus, communication device **102** is configured to recognize changes in the bandwidth and dynamically reallocate the bandwidth to more efficiently make use of communication link **106**.

Communication device **102** may be configured to dynamically allocate the bandwidth among various service classes or applications communicating over the network. A determination is made on whether the bandwidth capacity has changed **302**. This may occur, for example, as a result of environmental conditions that affect the quality of transmissions/reception or other factors that degrade or improve communication link **106** and affect the bandwidth. In one implementation, this determination may be made by tracking signal-to-noise ratio's and/or error rates on communication link **106**. For instance, an increase in the packet retries or receive/transmit errors indicates a decrease in bandwidth capacity.

The communication device then determines the transmission rate requirements of traffic in reallocating the bandwidth **304**. For instance, the maximum bandwidth allocations for each service class or application may simply be proportional to the original/previous maximum bandwidth allocation for each service class or application. Thus, when the bandwidth increases or decreases, the maximum percentage allocated to each service class or application remains the same. Alternatively, communication device **102** may also determine whether there have been changes in traffic requirements **306**. For instance, the type and/or number of applications communicating through communication device **102** over wireless communication link **106** may change over time. For example, communication device **102** may initially allocate fifty percent of the bandwidth of link **106** for voice (e.g., VOIP) communications and fifty percent for web browsing applications. However, usage information may indicate that voice communications account for greater bandwidth usage than web browsing applications over link **106**. Thus, better bandwidth usage may be achieved by reallocating the maximum bandwidth per service class **308** to improve overall QoS. For example, a greater bandwidth percentage (e.g., seventy percent) is allocated to voice communications versus web browsing applications (e.g., thirty percent).

Yet another implementation provides a discretionary denial-of-service to maintain QoS for a dynamic bandwidth. For example, if the maximum allocated bandwidth for a particular service class or application can only support two applications at their minimum communication rates, then communication device **102** may drop or deny service to any other application of the same service class that attempts to communicate over the allocated bandwidth. That is, rather than provide poor or ineffective service to all applications, communication device **102** limits the number of applications or communication sessions supported at any one time. This way, communication device **102** can at least guaranty a minimum transmission rate to some applications or services.

Yet another implementation provides for making the maximum bandwidth for a service class at least as large as the minimum bandwidth required for a single application or communication session. That is, rather than making a maximum bandwidth for a service class so small that it cannot adequately support even a single application, the maximum bandwidth is allocated such that it is at least as large as the minimum bandwidth required for that service class or application.

Yet another feature provides for making a maximum bandwidth allocation an integer multiple of the minimum required bandwidth for that particular service class or application. For example, allocating a maximum bandwidth that is 3.5 times the minimum required bandwidth for a service class may waste bandwidth when the communication channel is operating at full-capacity (e.g., three applications/sessions communicating at the minimum rate.). To make better use of the overall bandwidth, it may be beneficial to make the maximum bandwidth allocation for a service class an integer multiple of the minimum required bandwidth for that particular service class.

In some situations, the dynamic bandwidth may become so small that it becomes impossible to provide a minimum bandwidth required to support certain classes of services. For instance, the overall dynamic bandwidth may decrease so much that the maximum bandwidth allocated for a particular service class is less than the required minimum bandwidth for that service. In such situations, rather than allocating a useless amount of bandwidth to a particular service class, that bandwidth is reallocated to other service classes that can benefit or make use of that bandwidth. As the dynamic bandwidth increases, the denied service class may again receive a bandwidth allocation.

FIG. **4** illustrates a method for dynamic maximum packet sizing that may be implemented on a gateway, such as communication device **102**, to adjust QoS policy and address jitter in a communication link. Abrupt variations in the available bandwidth result in unwanted timing jitter (e.g., variations or instability in the duration of a specified time interval) of the transmission link, where transmission times increase and/or decrease. This increase/decrease in link transmission time has a negative impact on the delivery of time-sensitive information, such as voice over IP packets. In particular, it makes it difficult for the communication system to determine a maximum transmission delay so that it can guarantee delivery of high priority packets.

One solution to such link jitter is to adjust the maximum packet size of all information being transmitted so that the actual time of transmission (or transmission delay) stays below a particular threshold. A determination is made as to the current jitter of the communication link **402**. This may be done by measuring timing variations between received packets. Then, the current jitter is compared to the previous jitter **404** to determine if there has been a change in the communication link jitter **406**. If there has been a change in the communication link jitter, the maximum packet size of all packets transmitted is adjusted to compensate for the change in jitter **408**. For example, if the timing jitter has increased above a particular threshold (meaning that the maximum packet transmission delay or time has increased above a particular threshold), the maximum packet size of all packets across the communication link is reduced to maintain the maximum transmission time or delay approximately constant. In this manner, the system can have a guaranteed maximum transmission delay or time.

FIG. **5** illustrates a method for adaptive policing that may be implemented on a gateway, such as communication device

102, to adjust QoS policy. This feature monitors jitter in the link 106 and arranges the transmission order of packets according to their time-to-user or priority characteristics. When transmitting voice-over-IP (VOIP), for instance, jitter may be experienced over the link that may degrade the quality of the conversation. For example, given a 1,500 Byte IP packet and a 120 kbps return link rate, it takes over 100 milliseconds to send one packet. The VOIP packets would typically be interleaved between pluralities of other packets for other sessions. Jitter may cause some VOIP packets to experience noticeable delays and degrade a conversation. Thus, adaptive policing is implemented to counter this problem. A mechanism is provided to dynamically reset or adjust the quality of service (QoS) policy in order to control the network traffic based on preset guideline(s).

In one example, traffic is shaped by classifying it into a plurality of classes in ascending or descending priority. For instance, traffic may be classified, from highest priority to lowest priority, as follows: 1) voice control traffic, including Session Initiation Protocol (SIP) and network control packets; 2) voice-bearing traffic, including Real-time Transport Protocol (RTP) and voice carrying packets; 3) acknowledges, such as Internet Control Message Protocol (ICMP) and Transport Communication Protocol (TCP) ACK's; 4) web browsing—hypertext transfer protocol (HTTP)—and other interactive applications; and 5) all the remaining traffic.

The timing requirements (e.g., time-to-user requirements) or traffic priorities are determined for the various packets and/or session **502**. For example, text data packets may require guaranteed delivery but can withstand longer delays. Meanwhile, voice communications (e.g., VOIP packets) can withstand dropped packets but have shorter delays. Generally, prior knowledge of applications is necessary in order to properly shape the traffic priority.

The system may monitor a buffer to determine the characteristics of the packets therein. The presence of jitter in the communication link (e.g., link **106** in FIG. **1**) is also determined **504**. This may be done by measuring timing variations between received packets. If jitter greater than a particular threshold is detected **506**, then the order of packets in the buffer is adjusted to give time-sensitive packets greater priority **508**. That is, time-sensitive packets are moved ahead of some less time-dependent packets. The system then continues to monitor the timing requirements of packets and presence of jitter.

In one implementation, various fair queuing schemes (e.g., stochastic fair queuing) are applied to all queues such that the system randomly or pseudo-randomly extracts packets of different priority levels for transmission. This prevents high-priority packets from monopolizing the limited bandwidth to the detriment of other service classes or applications.

Yet another feature of adaptive policing limits low priority traffic to a transmission rate less than the link speed and limits their burst rates. In this manner, the QoS for higher priority traffic can be maintained.

FIG. **6** illustrates a communication system where real-time link status information can be shared across layers of a network stack. The network stack may be similar to an OSI model having an Application Layer (Layer 7) **604**, a Presentation Layer (Layer 6) **606**, a Session Layer (Layer 5) **608**, a Transport Layer (Layer 4) **610**, a Network Layer (Layer 3) **612**, a Data Link Layer (Layer 2) **614**, and a Physical Layer (Layer 1) **616**. Application layer **604** provides network services to end-users or applications. Presentation layer **606** converts the local data to a standard byte representation. Session layer **608** defines the format of the data sent over the connections. Transport layer **610** subdivides the content in a user buffer into network-buffer sized datagrams and enforces a desired transport protocol. Network layer **612** is responsible for routing or directing datagrams from one network to another. Data layer **614** defines the format of data on the network (e.g., data frame, packet, checksums, source and destination address, data, etc.) Physical layer **616** defines the physical media employed for communications.

One implementation provides a mechanism to collect real-time link status feedback of the physical (Layer 1) and data link (Layer 2) layers at the network layer (Layer 3). These network performance indicators are used at the network layer (Layer 3) in order to decide the optimal policy to police traffic through a gateway. That is, having real-time information about the link status may improve the performance of many of the QoS features described above. In the standard OSI model, this information is found in Layer 2 (Data Link layer.) However, QoS is typically implemented at higher layers, such as Layer 3 (Network layer). Thus, one feature of the invention provides for access to link status information, such as packet sizes, data rates, dropped packet statistics, etc., to be accessible at the Layer 3 or above. This may be done through software hooks that allow Layer 3 applications to retrieve link status information from Layer 2.

An alternative technique provides a live monitoring mechanism that collects network layer (Layer 3) performance information for different service classes and provides closed-loop real-time feedback to control the QoS policy. This technique isolates the network layer (Layer 3) policy from the underlining physical network (Layer 2) and makes this technique adaptive to an EVDO network and other types of networks.

FIG. **6** illustrates one example of a communication system configured to provide adaptive quality of service at a first and/or second communication systems **600** and **602** by implementing link status information sharing across a network stack. First and second communication systems **600** and **602** are communicatively coupled to each other via a network **618** (e.g., wired and/or wireless network) to transmit information. Each communication device or associated devices may implement a network stack that facilitates one or more of the QoS policy adjustment features described above. Thus, link status information from the Physical layer (1) and Data Link layer (2) may be accessible to Network layer (3) and used to improve communications at one or both sides of the communication link between communication devices A and B.

Communication systems **600** and **602** may include one or more systems that implement the network stack. For example, layers 1, 2, and 3 may be implemented on a modem, router, or gateway while layers 4, 5, 6, and 7 may be implemented on a personal communication device such as a mobile phone, computer, personal digital assistant, etc.

In one implementation, communication system **600** may be a gateway on an aircraft that serves one or more personal communication devices (e.g., cell phones or computers) in the aircraft and provides a communication link to devices other communication devices inside or outside the aircraft (e.g., to other devices on land, inside the same aircraft, or on other aircraft). Using status link sharing across network stack layers, communication system **600** may be configured to perform (1) dynamic maximum bandwidth reallocation, (2) dynamic maximum packet sizing, (3) adaptive policing, and/or (4) real-time link status feedbacks to make more efficient use of a bandwidth and adjust to transmission requirements as described above. Through the network stack one or more of these techniques may be implemented. These techniques may be applied at various layers of the network stack illustrated in FIG. **6** without departing from the invention.

FIGS. **7-11** illustrate examples of various other implementations to achieve various operations in accordance to the description above. In FIG. **7**, a communication gateway may comprise a receiver module **710**, an organizer module **720**, a monitor module **730** and an adjuster module **740**. Receiver module **710** is configured to receive digital information. Organizer module **720** is configured to organize the digital information into packets, where each packet associated with one of a plurality of service classes. Monitor module **730** is configured to monitor real-time characteristics of a dynamic communication link to identify a change in bandwidth. Adjuster module **740** is configured to adjust a quality of service policy to reallocate the maximum bandwidth per service class, if the bandwidth of the dynamic communication link changes.

FIG. **8** illustrates an apparatus comprising a receiver module **810**, a classifier module **820**, a monitor module **830**, an adjuster module **840**. Receiver module **810** is configured to receive digital information. Classifier module **820** is configured to classify the digital information into one or more service classes. Monitor module **830**, is configured to monitor real-time characteristics of a dynamic communication link having varying bandwidth. Adjuster module **840** is configured to dynamically adjust a quality of service policy for the one or more service classes according to the real-time characteristics of the dynamic communication link.

FIG. **9** illustrates an apparatus comprising a receiver module **910**, a segmenting module **920**, a monitor module, a determining module **940** and an adjustor module **950**. Receiver module **910** is configured to receive digital information. Segmenting module **920** is configured to segment the digital information into packets. Monitor module **930** is configured to monitor real-time characteristics of a dynamic communication link having varying bandwidth. Determining module **940** is configured to determine if timing jitter of the dynamic communication link has changed. Adjuster module **950** is configured to dynamically adjust a maximum packet length of the digital information to maintain a maximum packet transmission time approximately constant.

FIG. **10** illustrates another apparatus comprising a determining module **1010** configured to determine whether jitter is present in a dynamic communication link and a rearranging module **1020** configured to adaptively rearrange the order of digital information packets to give time-sensitive packets greater priority when jitter is present. FIG. **11** illustrates still another apparatus comprising an implementer module **1110** configured to implement two or more network stack layers to transmit digital information from one or more service classes across a dynamic communication link and a sharing module **1120** configured to share dynamic link status information from a first network stack layer with a second network stack layer.

It should be noted that the gateway and apparatus of FIGS. **7-11** are examples and may comprise other elements. Also, one or more of the elements of FIGS. **7-11** may be implemented together. Moreover, one or more of the elements of FIGS. **7-11** may be implemented by various means as necessary.

Accordingly, it should be noted that the foregoing embodiments are merely examples and are not to be construed as limiting the invention. The description of the embodiments is intended to be illustrative, and not to limit the scope of the claims. As such, the present teachings can be readily applied to other types of apparatuses and many alternatives, modifications, and variations will be apparent to those skilled in the art. For instance, one or more of the components and/or functions described herein may be combined into a single component or embodied in multiple components without departing from the invention.

What is claimed is:

1. An apparatus comprising:

an input interface to receive digital information transmitted on a dynamic communication link;

a processing unit coupled to the input interface, the processing unit configured to

organize the digital information into packets, each packet associated with one of a plurality of service classes;

monitor jitter and bandwidth of the dynamic communication link;

based on the monitoring, determine whether the jitter or the bandwidth has changed;

based on determining that the jitter has changed, adjust a maximum packet size of transmitted packets to maintain a maximum packet transmission time approximately constant; and

based on determining that the bandwidth has changed, dynamically adjust a quality of service policy of the plurality of service classes at least in part by proportionally reallocating a total bandwidth of the dynamic communication link according to previous maximum allocation percentages.

2. A communication gateway comprising:

means for receiving digital information transmitted on a dynamic communication link;

means for organizing the digital information into packets, each packet associated with one of a plurality of service classes;

means for monitoring jitter and bandwidth of the dynamic communication link;

means for determining, based on the monitoring, whether the jitter or the bandwidth has changed;

means for dynamically adjusting, based on determining that the jitter has changed, a maximum packet size of transmitted packets to maintain a maximum packet transmission time approximately constant; and

means for dynamically adjusting, based on determining that the bandwidth has changed, a quality of service policy of the plurality of service classes at least in part by proportionally reallocating a total bandwidth of the dynamic communication link according to previous maximum allocation percentages.

3. A non-transitory machine-readable storage medium storing one or more instructions which when executed by a processor cause the processor to:

monitor jitter and bandwidth of a dynamic communication link having varying bandwidth;

determine whether the jitter or the bandwidth has changed;

based on determining that the jitter has changed, adjust a maximum packet size of digital information received via the dynamic communication link to maintain a maximum packet transmission time approximately constant; and

based on determining that the bandwidth has changed, proportionally reallocating a total bandwidth of the dynamic communication link according to previous maximum allocation percentages.

4. The non-transitory machine-readable storage medium of claim **3**, wherein the one or more instructions when executed by the processor further cause the processor to dynamically adjust a quality of service policy associated with one or more of service classes assigned to the digital information, based on determining that the bandwidth has changed.

5. The non-transitory machine-readable storage medium of claim **4**, wherein the dynamically adjusting the quality of service policy includes reallocating the total bandwidth of the dynamic communication link according to current traffic demands over the dynamic communication link.

6. The non-transitory machine-readable storage medium of claim **4**, wherein the dynamically adjusting the quality of service policy includes denying service to new digital information in a service class if an allocated bandwidth is insufficient to support a minimum transmission rate for existing digital information in the service class.

7. The non-transitory machine-readable storage medium of claim **4**, wherein the dynamically adjusting the quality of service policy includes allocating a maximum bandwidth for each of the service classes that is equal to or greater than a minimum bandwidth necessary to support minimum transmission rates of information in each of the service classes.

8. The non-transitory machine-readable storage medium of claim **7**, wherein dynamically adjusting the quality of service policy further includes denying service to new digital information in a service class if an allocated bandwidth for the service class is insufficient to support a minimum transmission rate for existing digital information in the service class.

9. The non-transitory machine-readable storage medium of claim **3**, the one or more instructions when executed to further cause the processor to:

segment the digital information into packets; and

transmit the packets over the dynamic communication link according to a quality of service policy associated with the digital information.

10. The non-transitory machine-readable storage medium of claim **9**, wherein the quality of service policy is set at a network layer of a network stack.

11. A non-transitory machine-readable storage medium storing one or more instructions which when executed by a processor cause the processor to:

receive digital information over a dynamic communication link having varying bandwidth;

segment the digital information into packets;

monitor jitter and bandwidth of a dynamic communication link;

determine whether the jitter or the bandwidth has changed;

based on determining that the jitter has changed, dynamically adjust a maximum packet length of the digital information to maintain a maximum packet transmission time approximately constant; and

based on determining that the bandwidth has changed, proportionally reallocate a total bandwidth of the dynamic communication link according to previous maximum allocation percentages.

12. An apparatus comprising:

means for monitoring jitter and bandwidth of a dynamic communication link having varying bandwidth;

means for, based on the monitoring, determining whether the jitter or the bandwidth has changed;

means for, based on determining that the jitter has changed, adjusting a maximum packet size of digital information received via the dynamic communication link to maintain a maximum packet transmission time approximately constant;

means for, based on determining that the bandwidth has changed, proportionally reallocating a total bandwidth of the dynamic communication link according to previous maximum allocation percentages.

13. An apparatus comprising:

means for receiving digital information over a dynamic communication link having varying bandwidth;

means for segmenting the digital information into packets;

means for monitoring jitter and bandwidth of the dynamic communication link;

means for, based on the monitoring, determining whether the jitter or the bandwidth of the dynamic communication link has changed;

means for, based on determining that the jitter has changed, dynamically adjusting a maximum packet length of the digital information to maintain a maximum packet transmission time approximately constant; and

means for, based on determining that the bandwidth has changed, proportionally reallocating a total bandwidth of the dynamic communication link according to previous maximum allocation percentages.

14. The apparatus of claim **1**, wherein a status, including at least one of packet size, data rate or dropped packet statistics, of the dynamic communication link is retrieved by a network layer from a data link layer to determine an optimal policy for traffic on the dynamic communication link.

15. A non-transitory machine-readable medium having one or more instructions for dynamically adjusting maximum bandwidth allocations of a communication system, which when executed by a processor causes the processor to:

receive digital information;

classify the digital information into one or more service classes;

monitor real-time characteristics of a dynamic communication link having varying bandwidth;

dynamically adjust a quality of service policy for the one or more service classes according to the real-time characteristics of the dynamic communication link, the dynamically adjusting the quality of service policy of the one or more service classes including making a maximum bandwidth an integer multiple of a minimum required bandwidth for a particular one of the service classes;

determine whether jitter on the dynamic communication link has changed; and

if the jitter has changed, adjust a maximum packet size of the digital information to maintain a maximum packet transmission time approximately constant.

16. The apparatus of claim **1**, wherein the processing unit is configured to monitor the jitter at least in part by measuring timing variations between received packets.

17. The apparatus of claim **1**, wherein the processing unit is configured to monitor the jitter at least in part by monitoring a buffer.

18. The apparatus of claim **1**, wherein the processing unit is configured to compare a current jitter to a previous jitter to determine whether the jitter has changed.

19. The communication gateway of claim **2**, the means for monitoring the jitter including means for measuring timing variations between received packets.

20. The communication gateway of claim **2**, the means for monitoring the jitter including means for monitoring a buffer.

21. The communication gateway of claim **2**, the means for monitoring the jitter including means for comparing a current jitter to a previous jitter.

22. The non-transitory machine-readable storage medium of claim **3**, wherein the one or more instructions when executed by the processor further cause the processor to monitor the jitter at least in part by measuring timing variations between received packets.

23. The non-transitory machine-readable storage medium of claim **3**, wherein the one or more instructions when executed by the processor further cause the processor to monitor the jitter at least in part by monitoring a buffer.

24. The non-transitory machine-readable storage medium of claim 3, wherein the one or more instructions when executed by the processor further cause the processor to monitor the jitter at least in part by comparing a current jitter to a previous jitter.

25. The non-transitory machine-readable storage medium of claim 11, wherein the one or more instructions when executed by the processor further cause the processor to monitor the jitter at least in part by measuring timing variations between received packets.

26. The non-transitory machine-readable storage medium of claim 11, wherein the one or more instructions when executed by the processor further cause the processor to monitor the jitter at least in part by monitoring a buffer.

27. The non-transitory machine-readable storage medium of claim 11, wherein the one or more instructions when executed by the processor further cause the processor to monitor the jitter at least in part by comparing a current jitter to a previous jitter.

28. The non-transitory machine-readable storage medium of claim 11, wherein the one or more instructions when executed by the processor further cause the processor to dynamically adjust a quality of service policy associated with one or more of service classes assigned to the digital information, based on determining that the bandwidth has changed.

29. The apparatus of claim 12, the means for monitoring the jitter including means for measuring timing variations between received packets.

30. The apparatus of claim 12, the means for monitoring the jitter including means for monitoring a buffer.

31. The apparatus of claim 12, the means for monitoring the jitter including means for comparing a current jitter to a previous jitter.

32. The apparatus of claim 12, further comprising means for dynamically adjusting a quality of service policy associated with one or more of service classes assigned to the digital information, based on determining that the bandwidth has changed.

33. The apparatus of claim 13, the means for monitoring the jitter including means for measuring timing variations between received packets.

34. The apparatus of claim 13, the means for monitoring the jitter including means for monitoring a buffer.

35. The apparatus of claim 13, the means for monitoring the jitter including means for comparing a current jitter to a previous jitter.

36. The apparatus of claim 13, further comprising means for dynamically adjusting a quality of service policy associated with one or more of service classes assigned to the digital information, based on determining that the bandwidth has changed.

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